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EMPIRICAL ARTICLE

CHILD DEVELOPMENT

Early word learning is influenced by physical environments

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Abstract
During word learning moments, toddlers experience labels and objects in particular environments. Do toddlers learn words better when the physical environment creates contrasts between objects with different labels? Thirty-six 21- to 24-month-olds (92% White, 22 female, data collected 8/21–4/22) learned novel words for novel objects presented using an apparatus that mimicked a shape-sorter toy. The manipulation concerned whether or not the physical features of the environments in which objects occurred heightened the contrasts between the objects. Toddlers only learned labels for objects presented in environments where the apparatus heightened the contrast between the objects (b=.068). These results emphasize the importance of investigating word learning in physical environments that more closely approximate young children's everyday experiences with objects.

Learning concrete nouns rests on children's ability to connect a label to a particular set of objects in the world. For decades, language development research has investigated how young children contend with the challenges inherent in identifying the correct referent for a new word. This body of literature has revealed a variety of factors that impact how successful a given word learning moment may be. For example, the quality of caregivers' linguistic input, along with the social cues that caregivers provide (such as pointing), affects children's ability to identify referents and learn words (e.g., Cartmill et al., 2013; Choi & Rowe, 2021; Salo et al., 2019; Tamis-Lemonda et al., 2013). Additionally, the perceptual salience of objects and children's interest in particular object categories can direct their attention to the appropriate referent during word learning (e.g., Ackermann et al., 2020; Pruden et al., 2006; Scofield et al., 2011).

Importantly, children experience all of this linguistic, social, and perceptual input within cluttered surrounding environments and meaningful contexts (Clerkin et al., 2017; Clerkin & Smith, 2022; Fausey et al., 2016). For example, a caregiver and a child might be eating a meal together at a table laden with foods and many other objects, and the caregiver might provide the labels "fork" and "spoon." The child must not only establish the correct mapping from the word "fork" to its referent, but also appropriately separate this mapping from the mapping between the word "spoon" and its referent. In other words, as a part of the word learning process in cluttered environments, children must distinguish between objects that are associated with different labels. Understanding how features of the physical environment might help or hinder young children's ability to successfully differentiate between objects with different labels will provide a more complete picture of the naturalistic word learning process.

Prior research has demonstrated that opportunities to contrast objects with different labels and in different categories support successful word learning and object categorization. For example, 10-month-old infants were able to form two distinct novel object categories when they were presented with novel object exemplars in cross-category pairs, such that they had the opportunity to directly compare the exemplars side by side (Sučević et al., 2022). However, infants were unable to form two distinct novel object categories when presented with the same exemplars one at a time. Similarly, 10-month-old infants were able to demonstrate word learning for two perceptually distinct object categories (i.e., "horse" and "airplane"), but were unable to learn words for two perceptually similar object categories (i.e., "horse" and "cow;" Taxitari et al., 2020). In both cases, word learning was

Abbreviation: MB-CDI, MacArthur-Bates Communicative Development Inventory.

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more successful when infants had access to the perceptual contrast between objects. Network analyses of vocabulary development reveal a similar pattern of results: the perceptual distinctiveness of an object predicts the age of acquisition for its label (Engelthaler & Hills, 2017). Labels for objects that are more perceptually distinct from all other objects in a network are learned earlier than labels for objects that are more perceptually similar to the other objects in the network. Taken together, this work suggests that establishing clear contrast between objects with different labels—through opportunities for comparison or due to the distinctiveness of the objects' perceptual features—sets the stage for successful word learning.

Another way that contrasts between objects with different labels might become evident to toddlers, and therefore aid in word learning, is by observing how different objects behave within their surrounding environment. For example, when hearing the words "fork" and "spoon" in a naturalistic mealtime context, a child might see a fork pick up a piece of fruit or a spoon used to eat soup. In fact, it is in just these moments—when toddlers and their caregivers are manipulating and interacting with objects—that caregivers often provide labels for objects (Custode & Tamis-LeMonda, 2020; Fausey et al., 2016; Long et al., 2022; West & Iverson, 2017). The surrounding environment also influences the words that caregivers provide in their input. For example, caregivers tend to talk about food-related words in the kitchen during mealtimes and body-related words in the bathroom during bath time (Custode & Tamis-LeMonda, 2020; Tamis-LeMonda et al., 2019). Perhaps for this reason, the surrounding environment also influences which words toddlers learn. For example, toddlers learn words earlier and more easily for objects that are encountered in predictable and specific environments (Benitez & Saffran, 2018; Roy et al., 2015).

Importantly, the surrounding environment not only plays a role in organizing high-level activities (e.g., eating often occurs in the kitchen) but also affects the kinds of low-level actions that can be performed with specific objects. For example, a plate can be easily balanced on the hard, flat surface of a kitchen table but not on the soft, narrow, and curved arm of a couch. Furthermore, the features of objects themselves, such as their shapes, impact how they are used. For example, a fork can pick up a piece of fruit because of its tines, while a spoon can be used to eat soup because of its rounded, concave end. Previous research has demonstrated that toddlers are sensitive to this correspondence between what an object can do and the features the object has, and toddlers can use these correspondences to inform categorization and word learning (Booth, 2006; Kemler Nelson et al., 2000). For example, after observing objects perform functions that were causally related to the objects' unique shapes, toddlers were more likely to categorize the objects on the basis of shape than if they observed the objects performing functions unrelated to their shape (Ware & Booth, 2010). This result suggests that observing objects interact with their environment in ways that are related to the objects' features, such as shape, heightens toddlers' attention to these features.

These considerations suggest that the ways in which objects can be used are determined by features of the physical environment, features of the object, and the relationship between the two. Therefore, the physical features of the environment in which toddlers encounter objects might scaffold word learning in two related ways. First, environments with physical features that afford different actions for different objects may provide an additional element of general contrast between objects. Second, environments that contain physical features that are tightly related to features of the objects that interact with them may serve to draw attention to key contrastive features of different objects (such as their shapes).

The physical environments in which objects are embedded appear to be uniquely positioned to create contrast between objects and scaffold word learning. However, objects with different labels may not always interact with their surrounding environment in different ways. In some environments, objects with different labels do different things; when eating soup, a spoon can be used as an effective utensil but a fork cannot. But, in other environments, objects with different labels do the same thing. For example, when eating mashed potatoes, a spoon and a fork are both effective utensils. Therefore, some environments establish contrast between objects with different labels while other environments fail to establish this contrast.

In the current study, we asked whether encountering objects in an environment with physical features that establish contrast between objects with different labels facilitates word learning. Toddlers were exposed to labels for novel objects in two different physical environments. In one environment, each object interacted with the environment differently, related to each object's unique shape. In the other environment, the objects interacted with the environment in the same way regardless of their unique shapes. Thus, one physical environment established contrast between the objects and drew attention to their shapes while the other did not. We manipulated the physical word learning environment within-subjects, using a novel paradigm modeled after a "shape-sorter" toy (see Figure 1). Two of the novel objects were shown being placed into a box through different openings that matched the shape of each object (*Contrastive* condition). The other two novel objects were shown being placed into a box through the same large opening that did not match the shape of either object (*Non-Contrastive* condition). Each object was labeled with a unique novel word, and word learning was measured using a looking-while-listening eye-tracking paradigm. We predicted that word learning would be facilitated for objects presented in the physical environment that established contrast between the objects and their shapes compared to the environment that did not.

The way objects interact with an environment can be governed by many different features of objects, including

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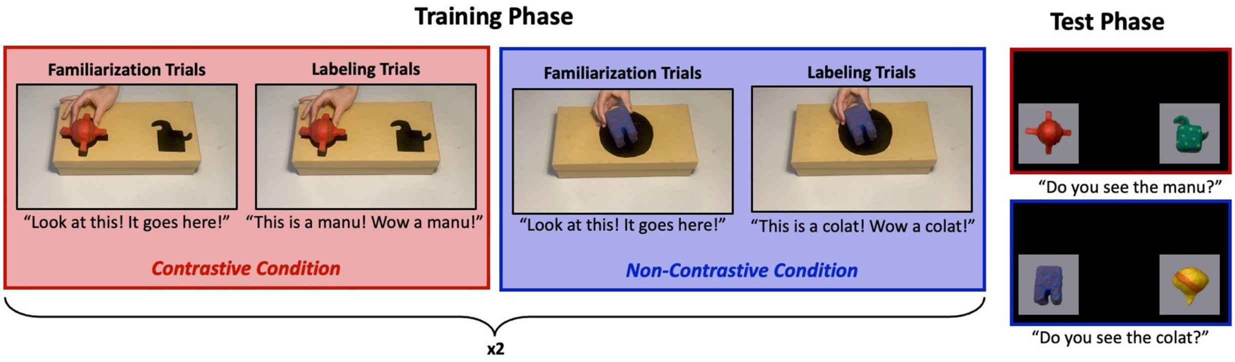

FIGURE 1 Examples of familiarization, labeling, and test trials in each condition.

shape, color, material, size, etc. For the purposes of this study, we chose environments in which objects' interactions were governed by their shape, given the relevance of shape to learning concrete nouns (e.g., Landau et al., 1988). For example, what determines whether a utensil is called a "spoon" or a "fork" is its shape. The more attentive toddlers are to shape, the better word learners they are (e.g., Smith et al., 2002; Son et al., 2008). In other words, drawing toddlers' attention to the shape of an object, which is often the feature most relevant for correctly differentiating between and extending words, supports word learning. Thus, creating contrast between objects on the basis of shape is likely important for successful word learning.

We were also interested in exploring whether potential individual differences in attention, including attention to shape, might be related to word learning performance. Previous research suggests that the structure of toddlers' vocabulary, specifically the proportion of words in their vocabulary that refer to categories of objects defined by their shape, is related to how much toddlers attend to object shape during word processing (Perry & Saffran, 2017; Perry & Samuelson, 2011). Therefore, we measured toddlers' productive vocabulary to determine whether the extent to which toddlers' vocabularies were dominated by words denoting shape-based categories influenced their word learning in our paradigm. We also explored differences in visual attention during learning in each of our conditions. All hypotheses and analytic approaches were pre-registered and can be accessed along with all stimuli, data, and analysis scripts on the Open Science Framework (https://osf.io/zvbf2/).

METHOD

Participants

The final sample included 36 toddlers between 21 and 24 months (M_{age} = 21.83, 22 female). This sample size was determined using an a priori power analysis in G*Power to achieve 90% power based on the effect sizes obtained in similar novel word learning paradigms (Benitez & Saffran, 2018; Pomper & Saffran, 2019). All toddlers were full-term, had no vision or hearing loss, and were monolingual English-learners without substantial exposure to a second language (<10 h per week). Thirteen additional participants were excluded from analysis due to insufficient usable data (see criteria below) in one or both experimental conditions (n = 12) or due to technical error (n = 1). Thirty-three of the toddlers were White, and three were mixed race; two toddlers were Hispanic, and 34 were non-Hispanic. Participants were recruited from the local area in a midwestern city using an existing database of interested families. All parents provided written informed consent prior to participation, and all experimental protocols were approved by the local Institutional Review Board.

Stimuli

Novel objects and labels

Toddlers were taught novel labels for four novel objects created with sculpting material (see Figure 1). The four objects were yoked into two pairs; each pair was presented in one of the two within-subjects conditions (*Contrastive* and *Non-Contrastive*). Assignment of object pairs to conditions was counterbalanced across participants. Novel labels (*colat*, *manu*, *tever*, *wiso*) were selected from the Novel Object and Unusual Name Database; all labels were disyllabic and equated on phonotactic probability (Horst & Hout, 2016).

Familiarization trials

Familiarization trials were used to introduce toddlers to the interactions between the novel objects and the physical environments in which they were embedded before they heard the label for each object. Familiarization

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trials included videos of a hand placing an object into a box through an opening with an accompanying descriptive utterance (e.g., *This is cool! It goes here!*). The box used in the *Contrastive* condition contained two openings in its cover, each one matching the shape of one of the two objects in that condition. Each object was placed into the opening that matched its shape. The box used in the *Non-Contrastive* condition had one large round opening in its cover, which did not match the shape of either object. Both objects in the *Non-Contrastive* condition easily fit through the opening and both were placed into the box through it.

Labeling trials

Labeling trials consisted of videos similar to those in the Familiarization trials but with the objects labeled. The objects were assigned to the same conditions as in the Familiarization trials. On each trial, a novel object was placed into an opening in either the *Contrastive* or the *Non-Contrastive* apparatus and labeled 3 times (e.g., *This is a manu! Wow, a manu! It's a manu!*).

Test trials

Toddlers completed familiar word test trials and novel word test trials. Familiar word trials were presented at the beginning of the test to introduce toddlers to the task and interspersed throughout the test to maintain interest. On familiar word test trials, two familiar objects were pictured on gray backgrounds, one on each side of the screen, and toddlers heard a sentence labeling one of them (e.g., "Do you see the apple?"). The familiar words tested included apple, ball, book, and shoe. On novel word test trials, a pair of novel objects from training were presented on gray backgrounds, one on each side of the screen (see Figure 1). Object pairs were yoked such that the two objects presented in the *Contrastive* condition were always tested together and the two objects presented in the *Non-Contrastive* condition were always tested together. On each test trial, toddlers heard a sentence labeling one of the objects (e.g., "Can you find the *manu*?"). Audio stimuli were recorded by a female native English speaker in child-directed speech and normalized in duration and average intensity (70 dB) using Praat. Each test trial was 5000 ms. Each trial began with the two objects presented on the screen in silence for 1500 ms. The duration of the carrier phrase of the test sentences (e.g., "Do you see the," "Can you find the," etc.) was normed to 1057 ms. The duration of the target word (e.g., "*manu*") was normed to 943 ms. Once the test sentence audio ended, the images of the objects remained on the screen for an additional 1500 ms.

Design and procedure

The study was administered in a soundproof booth. Toddlers sat in their caregiver's lap approximately one meter from a 55″ LCD screen. Eye-movements were captured using a Tobii X2-60 eye-tracker with a 60 Hz sampling rate, which was calibrated to each toddler before the study using a 5-point calibration procedure (red pulsing dots with an attention-grabbing noise). Looking behavior was also recorded using a digital camera mounted below the LCD screen to capture usable data in the event that the eye-tracker failed. Caregivers also completed a demographic questionnaire, a study-specific survey examining toddlers' experience with shape-sorter toys, and a vocabulary inventory (MacArthur-Bates Communicative Development Inventory [MB-CDI]: Words and Sentences; Fenson et al., 1994).

The experiment consisted of a training phase and a testing phase. The training phase was split into four blocks; each block included Familiarization trials (4500 ms long) and Labeling trials (7500 ms long). Training blocks alternated between the two within-subjects conditions (*Contrastive* and *Non-Contrastive*), and order was counterbalanced across participants. The first two training blocks consisted of 2 Familiarization trials (1 for each object) followed by 4 Labeling trials (2 for each object). The second two training blocks consisted of 2 Familiarization trials (1 for each object) followed by 2 Labeling trials (1 for each object). Therefore, toddlers were presented with a total of 8 Familiarization trials and 12 Labeling trials. Attention-getter videos were included between training blocks to maintain interest. Following these four training blocks, participants completed the test phase with 20 trials (4 familiar word and 16 novel word trials). Two familiar word trials were presented at the beginning of the test and the other two were interspersed throughout. Each novel object-label pair was tested four times. The order in which objects in the *Contrastive* condition and objects in the *Non-Contrastive* condition were tested was pseudo-randomized and the target object appeared on the left and right side of the screen equally frequently.

Measures

Gaze behavior

To assess word learning accuracy at test, fixations on the target and distractor object on novel word trials were measured during a critical time window: 300 to 1800 ms after the onset of the target word (Fernald et al., 2008). For toddlers who did not contribute sufficient eye-tracking data (i.e., did not contribute at least 50% of frames for at least four test trials in each condition; $N=19$), video recordings were manually coded offline frame-by-frame

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(33 ms) for left and right looking by trained coders using Peyecoder (Olson et al., 2020). To measure reliability, 25% of the manually coded participants were independently recoded. Coders agreed on the gaze location for 98.0% of all frames and agreed within one frame on 95.1% of all shifts in gaze.

Parent report measures

Productive vocabulary was measured via parent report on the MB-CDI Long Form (Fenson et al., 1994). Parents also completed a study-specific survey about their child's experience with shape-sorter toys. Specifically, the survey asked parents to report whether or not their child plays with shape sorter toys and, if so, to report how frequently they do so on a Likert scale.

Vocabulary structure

To obtain a measure of the extent to which toddlers' existing vocabularies were organized by object shape, we calculated a shape-based vocabulary score for each toddler. Words refering to categories of solid objects defined by their shape (e.g., *ball* refers to a category of objects that are spherical in shape) are considered to be shape-based nouns. Existing adult ratings have coded each noun on the MB-CDI in terms of their organizing property (Perry & Samuelson, 2011; Samuelson & Smith, 1999). Using these adult ratings and parents' responses on the MB-CDI, we were able to calculate the proportion of nouns toddlers were reported to know that are shape-based nouns. However, this measure is highly correlated with overall noun vocabulary size. To obtain a measure of shape-based vocabulary that is independent of vocabulary size, consistent with previous investigations of toddlers' shape-based vocabulary, total vocabulary size was regressed out of the proportion of shape-based nouns in toddlers' productive vocabularies (Perry & Saffran, 2017). The resulting residuals were used as a measure of each toddler's shape-based vocabulary that was independent of total vocabulary size.

RESULTS

All analyses were carried out using linear mixed-effects models regressing word learning accuracy for each test trial on condition. Models with the maximal random effects structure, a by-subject random intercept and by-subject random slope for condition, did not converge. Following recommendations for resolving convergence errors in linear mixed-effects models, the random effects structure was simplified and only included a by-subject random slope for condition (Barr et al., 2013; Brauer & Curtin, 2018; Muradoglu et al., 2023). Models were run with condition dummy-coded (0 for one condition and 1 for the other) to investigate the condition effect and accuracy was coded with an offset of −0.5 such that 0 is equal to chance performance to determine whether word learning accuracy was above chance in each condition. To explore potential sources of variability in toddlers' word learning accuracy, between-subjects variables of interest (e.g., shape-based vocabulary) were added to the model. All analyses were completed in RStudio (1.1.463) using the lme4 package (1.1–26).

Our main pre-registered hypothesis concerned the influence of the physical features of the environment on toddlers' word learning. We compared word learning performance in the *Contrastive* condition, in which the physical features of the environment established both general contrast between the objects (each object fit into a different opening) and shape-based contrast (the openings matched the shape of each object), versus the *Non-Contrastive* condition, in which the physical features of the environment did not establish any contrast between the objects (each object fit into the same opening that did not match the shape of either object). We predicted that toddlers would demonstrate higher accuracy for novel object-label pairings that were taught in the *Contrastive* condition compared to the *Non-Contrastive* condition. Accuracy scores (Figure 2), as well as visual inspection of the time course of fixations during the test trials (Figure 3), suggest that toddlers looked more to the target object after hearing its label for objects trained in the *Contrastive* condition compared to the *Non-Contrastive* condition. The within-subjects effect of condition was marginally significant: $b = .071$, $F(1, 33.95) = 3.97$, $p = .054$. We next ran planned comparisons to determine whether word learning accuracy exceeded chance in each condition. Accuracy was significantly above chance in the *Contrastive* condition, $b = .068$, $F(1, 115.1) = 7.59$, $p = .0068$, but was not significantly different from chance in the *Non-Contrastive* condition, $b = -.0028$, $F(1, 112.1) = 0.014$, $p = .91$. These results suggest that toddlers successfully learned novel object-label pairings in the *Contrastive* condition but not in the *Non-Contrastive* condition. However, evidence for higher accuracy in the *Contrastive* condition than the *Non-Contrastive* condition is less robust, given that the effect of condition in the linear model was marginal.

We also performed exploratory analyses to investigate individual-difference variables that might explain additional variance in toddlers' word learning accuracy over and above the effect of condition; these variables included age, sex, total vocabulary size, shape-based vocabulary, and shape-sorter toy experience. When added to the linear mixed-effects model with condition, none of these variables had a significant effect on word learning accuracy (all p's > .05). In addition, likelihood ratio tests confirmed that linear mixed-effects models including condition and each covariate individually, as well as all covariates together, did not explain significant

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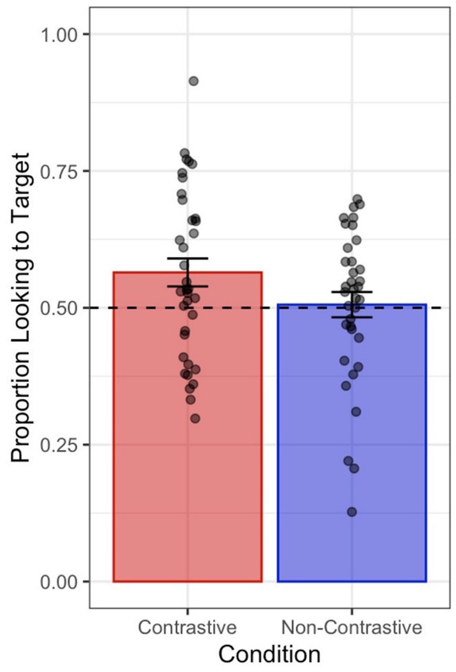

FIGURE 2 Mean proportions of looks to target averaged across the critical window (300–1800 ms after target word onset) of test trials in the Contrastive (in red) and Non-Contrastive condition (in blue). Data points represent the mean proportion of looks to target for each participant, averaged across trials in each condition. Error bars represent ±1 SE. The dashed horizontal line at 0.5 indicates chance performance (i.e., looking equally to the target and distractor).

additional variance compared to the original model that included only condition as a predictor (all p's > .05).

Cluster-based permutation analysis

To further investigate the effect of condition on word learning accuracy, we performed an exploratory cluster-based permutation analysis. Rather than testing for a condition effect on a measure of accuracy that is collapsed across our critical window of analysis (300–1800 ms), this approach allows us to test for a condition effect at smaller time-scales within this window and examine the condition effect across time. For this analysis, we conducted a t-test for each 33 ms time bin, which was the frame rate of our gaze coding, across our critical window from 300 to 1800 ms (45 separate tests, corrected for multiple comparisons). Each t-test determined whether word learning accuracy was significantly different between conditions in that particular 33 ms time bin. This allowed us to identify clusters of adjacent time bins within our critical window where there were significant effects of condition. We then summed the t values within the largest cluster. To determine the likelihood of observing a cluster of significant effects of that size, the data were reshuffled randomly 1000 times and the largest cluster of significant effects in each of the permuted data sets was calculated. The resulting p value represents the proportion of permuted cluster t values that were greater than the observed cluster t value in the original data.

The results of the cluster-based permutation analysis revealed a significant cluster for the effect of condition on word learning accuracy during the first portion of the critical window (300–833 ms after target word onset, t = 60.14, p = .016; see Figure 2). These data suggest that there is an effect of condition early in lexical processing; immediately following target word onset, word recognition was more accurate for labels taught in the *Contrastive* condition compared to the *Non-Contrastive* condition.

Training phase analysis

Finally, we examined whether the difference in word learning performance between the conditions could be explained by differences in visual attention to the training phase videos. There were no significant condition differences in total attention to the screen. There were condition differences in the amount of time toddlers looked at the object during the Labeling videos, with toddlers looking more at the object in the *Non-Contrastive* condition than the *Contrastive* condition; this looking behavior was not significantly related to test performance (see Supporting Information for more details and a graphical representation of the data).

DISCUSSION

As young children learn new words, they encounter objects in rich, dynamic environments. These environments can be characterized by high-level features, such as the location where a word learning interaction is occuring (e.g., the kitchen), as well as low-level features, such as the physical properties of the space in which objects are interacting during word learning. The current study aimed to investigate whether toddlers' early word learning is influenced by the physical features of the environment that objects are presented in. Specifically, we asked whether word learning is facilitated when word learning occurs within an environment that affords different actions for differently shaped objects. We manipulated the extent to which the physical environment—a shape-sorter-style apparatus—established contrast between objects with different labels based on the way the objects could interact with the environment. Toddlers received labels for novel objects and viewed the objects being placed into the apparatus through two different openings that uniquely matched their shape (*Contrastive* condition) or through the same single opening that would fit any of the objects and did not match their shape (*Non-Contrastive* condition). On the test trials, toddlers were above chance

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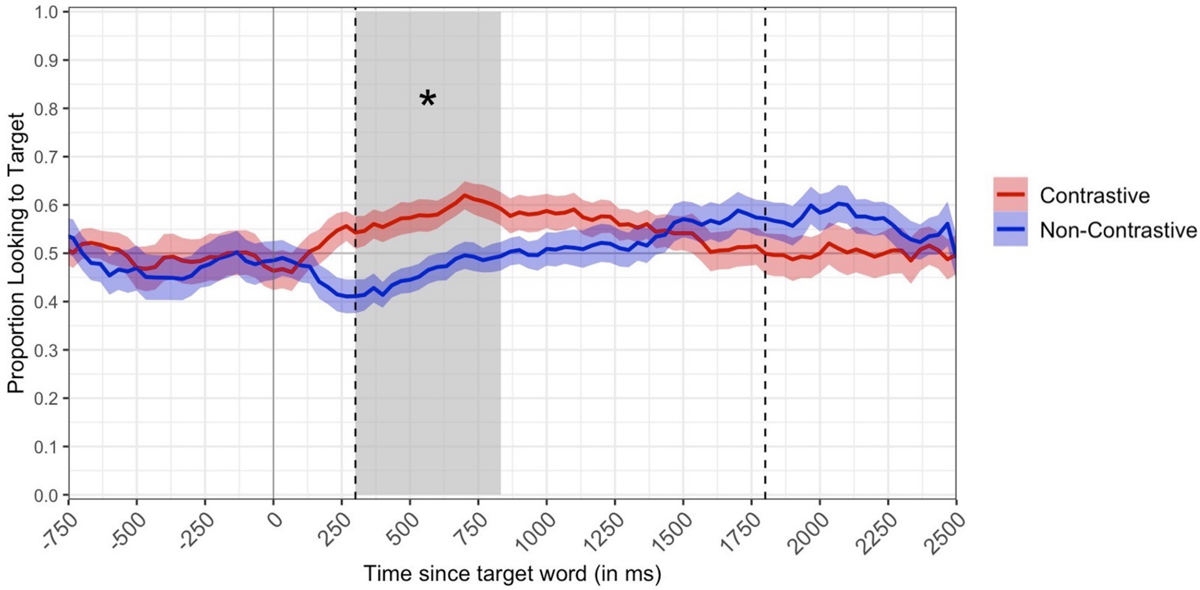

FIGURE 3 Time course of looks to target during test trials as a function of time (ms since target word onset) and condition (Contrastive in red and Non-Contrastive in blue). Solid lines represent the proportion of fixations to the target, averaged across participants. The ribbons around the lines represent ±1 SE. The horizontal line at 0.5 is chance performance. The shaded portion (300–833 ms) indicates the significant cluster identified from the permutation analysis.

in fixating the target novel object for object-label pairs taught in the *Contrastive* condition, but they were not above chance for object-label pairs taught in the *Non-Contrastive* condition. Furthermore, toddlers' average accuracy in fixating the target object across the critical window was higher in the *Contrastive* condition than the *Non-Contrastive* condition, though this difference was only marginally significant. Examining the condition effect at more precise time-scales, an exploratory follow-up cluster-based permutation analysis revealed that toddlers fixated the target object significantly more in the *Contrastive* condition than the *Non-Contrastive* condition specifically during the first part of the target window (300–833 ms after target word onset). Thus, our results are consistent with our hypothesis that learning words in environments with physical features that establish and highlight contrast between objects with different labels facilitates toddlers' learning of those labels. In particular, the results of the cluster-based permutation analysis suggest that toddlers show improved recognition of these labels in the early stages of comprehension, directly after hearing the target word.

These findings contribute to a growing body of work investigating the environments where children's word learning unfolds in their day-to-day lives. Infants' early everyday experiences with objects are frequently cluttered, with multiple objects visible, but organized within particular environments, for example, the highchair at mealtimes (Clerkin et al., 2017; Clerkin & Smith, 2022). As infants enter toddlerhood, they accumulate experience watching others manually manipulate objects and also manipulate objects themselves within these environments (Fausey et al., 2016; Schatz et al., 2022). The current work suggests that the unique and systematic ways that objects are able to interact within these environments, specifically the ways in which the physical features of the environment afford certain actions for differently shaped objects, may serve as important scaffolding for toddlers' word learning. Observing objects interacting with a physical environment in different ways may help to individuate objects and draw attention to their distinguishing features, like shape, establishing contrast between objects and drawing attention to valuable information for learning. Exactly what types of physical environments might be most supportive for word learning, and what features of objects might be most valuable to draw attention to, provide promising avenues for future work.

Given that the *Contrastive* condition increased the contrast between the two objects and the *Non-Contrastive* condition reduced the contrast between the two objects, it could be the case that the effect of condition was due to enhanced learning in the *Contrastive* condition, hindered learning in the *Non-Contrastive* condition, or a combination of the two. Future work can examine these possibilities by including a neutral condition without any surrounding physical environment, therefore neither highlighting nor obscuring contrast between the objects. Furthermore, the *Contrastive* condition increased the contrast between the objects compared to the *Non-Contrastive* condition in two ways. First, the objects were placed into two different openings rather than the same opening, establishing general contrast in the action performed by each object. Second, the two openings were different shapes that matched the shape of each object, drawing attention to

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the objects' different shapes. Therefore, in the current design, we cannot conclude whether improved learning in the *Contrastive* condition was driven by the fact that the objects generally interacted with the environment in different ways or due to the fact that the way the objects interacted with the environment was specifically related to their unique shapes. Future work could disentangle these potential mechanisms by testing a third condition in which objects are placed into different openings, but the shape of the opening is unrelated to the shape of the object.

It is also important to note that the shape-sorter paradigm used in the current study investigates the effect of environments that draw attention to one specific contrastive visual feature: shape. Shape is a particularly important organizing feature of early-learned words because it is often shared among objects with the same label (Jones & Smith, 2002; Landau et al., 1988). Thus, drawing attention to objects' unique shapes may be particularly beneficial for early word learning. However, the hypothesis examined in the current work—namely, that the physical features of the environment play an important role in differentiating objects and drawing attention to their unique features—is not necessarily specific to shape. For example, an environment with physical features that draw attention to other differentiating features of objects like material or color might improve word learning in the same way that physical environments that draw attention to objects' shapes do. Interestingly, in the current task, individual differences in toddlers' word learning performance were not related to their existing shape-based vocabulary. Previous work has demonstrated that toddlers' shape-based vocabulary impacts their attention to shape during word recognition and word learning (Perry et al., 2016; Perry & Saffran, 2017; Perry & Samuelson, 2011). Therefore, the fact that shape-based vocabulary was not related to toddlers' word learning performance in the current task might suggest that observing objects interacting with the physical environment in unique ways that are related to their unique shapes may be impacting word learning in ways over and above just drawing attention to shape. Furthermore, this effect may not be specific to physical environments in which objects' interactions are dictated by their unique shape, but a more general effect whereby environments in which objects interact differently, regardless of the feature that governs these interactions, support word learning. Future work should explore whether physical environments in which objects' interactions are dictated by other features of objects, such as texture, material, or color similarly influence word learning.

In our analyses of eye-gaze during the training phase, we considered alternative explanations for toddlers' heightened performance in the *Contrastive* condition. The results suggest that the condition differences cannot be explained by toddlers' visual attention—the amount of looking to the screen or to the object during learning. Instead, we propose that toddlers are encoding the objects differently in the *Contrastive* and *Non-Contrastive* conditions. In particular, the *Contrastive* condition may support toddlers in encoding representations of each novel object-label pairing that are more distinct from one another, thus making it easier to individuate the objects and leading to better word learning. In comparison, the *Non-Contrastive* condition may result in toddlers encoding representations of each object-label pairing that are more similar to one another. Furthermore, these representations may include information beyond just the object-label mapping, for example, the object's function or the semantic category it belongs to. These other aspects of representation may be similarly encoded as more distinctive in the *Contrastive* condition and less distinctive in the *Non-Contrastive* condition.

In the current paradigm, toddlers' word learning was tested using the same exemplars that they were shown during training and therefore, from the current data, we cannot determine exactly what information toddlers encoded about the trained objects. Examining toddlers' extension of learned words to novel exemplars could further clarify the mechanism by which physical environments might scaffold word learning. To successfully extend words to novel exemplars, children must identify which features of the object determine its label (i.e., for foods, material often determines their appropriate label, but for artifacts, shape is relevant; Booth & Waxman, 2002; Perry et al., 2014). The addition of test trials with novel exemplars to the current paradigm would provide a way to examine whether toddlers' generalization of novel words is influenced by the physical features of the environment they are learned in. If the *Contrastive* condition specifically supports toddlers in encoding representations of the objects' distinctive shapes, one might expect that toddlers would be more likely to extend the labels taught in this condition to novel exemplars that share the same shape as the originally trained object compared to exemplars that share a different feature, such as color. Similarly, might a toddler who learns an object-label pairing in an environment with physical features that differentiate objects on the basis of texture be more likely to extend its label to other objects with the same texture, rather than shape? Answering these questions will help improve understanding of the role of the physical environment not only in facilitating simple object-label mappings, but also in scaffolding word meanings and category development.

Importantly, the participants in this study were largely White toddlers living in a midwestern city. Their prior experiences with artifacts, including toys like shape-sorters (per caregiver report, almost all of our participants had played with shape-sorters previously), may have influenced their performance on this task relative to toddlers

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in other cultures and communities, who may have less exposure to objects of this kind. As research in this area develops, it will be important to consider generalizability to other types of physical environments and the myriad ways in which they may support word learning.

CONCLUSIONS

To our knowledge, this is the first study of its kind to directly manipulate the physical features of the environment around objects, such that the different shapes of objects with different labels were either foregrounded or backgrounded, and measure the impact on early word learning. The current paradigm begins to approximate the types of dynamic interactions between objects and their environments that children experience during word learning moments in their day-to-day lives. To successfully map labels to objects, toddlers must encode a representation of the object that a novel label maps onto. This process is facilitated for objects that are particularly distinctive. Thus, environments with physical features that create contrast between objects may provide a valuable source of data to help toddlers distinguish between objects with different labels and establish stronger object-label mappings.

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CONFLICT OF INTEREST STATEMENT

None declared.

DATA AVAILABILITY STATEMENT

The analyses presented here were preregistered. The data and analytic code necessary to reproduce the analyses presented in this paper are publicly accessible. The materials necessary to attempt to replicate the findings presented here are also publicly accessible. The preregistration, data, analytic code, and materials are available at the following link: https://osf.io/zvbf2/.

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